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USE OF CORUNDUM CERAMICS FOR FINE MILLING OF VARIOUS MATERIALS

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The wear resistance of corundum milling bodies developed by the authors is estimated compared to foreign analogs. It is established that domestic ceramics, with respect to its abrasion rate in milling electrocorundum and quartz sand, is not inferior to foreign ceramics. The kinetics of milling the specified materials is analyzed.

The contemporary phase of engineering calls for new types of ceramics with a controllable microstructure and steady physicochemical properties. One of the challenges of the domestic science of materials is the development of wear-resistant ceramics which could be successfully used, for instance, as mill lining elements and milling bodies.

The analysis of publications dedicated to this problem suggests that the research on wear-resistant materials is related to improving the properties of ceramics produced by mullite-corundum crystallization and also to developing new materials whose main crystalline phase is corundum. At present it is obvious that the former line of research does not allow for qualitative improvement of wear resistance, The abradability of the best materials of this class in mills is 0.02 %/h (experimental milling of quartz sand), which is inadmissible for contemporary conditions [1]. Apparently, promising research directions for developing ceramics with abradability below 0.01 %/h include the increase in the amount of corundum in material, as well as controlling material microstructure by introducing special modifying additives that crystallize in firing and form phases with a sufficiently high hardness. Eutectic additive compositions are especially interesting in this respect [2].

Based on the above principles, researchers at the D. I. Mendeleev Russian Chemical Engineering University have developed ceramic material Sh-2 containing 95% Al_2O_3 sintering at 1500°C with an average density of 3.73 g/cm^3 [3].

The purpose of our study is to estimate the wear resistance of milling bodies made of the Sh-2 material and to compare the obtained results with the wear resistance of foreign analogs. Such analog used in our study was Alubit-90 ceramic produced by the Industrie Bitossi SpA (Italy) for milling bodies, which is extensively used in Europe. Furthermore, the target of the study included the analysis of milling kinetics for different types of materials, which were represented by electromelted corundum (EMC) and quartz sand.

As for the phase composition of Alubit-90 ceramic, its matrix is represented by corundum crystals of the isometric (up to 3 μm) and elongated-prismatic shape with the longer axis size of 8 – 10 μm. Two phases of needle-shaped crystals of size less than 1 μm, one of which contains SiO_2, are formed on the periphery of the corundum crystals in the amount around 15 vol.%. Glass is absent. The size of round sealed intercrystalline pores is 5 – 6 μm and their quantity is up to 1.5 vol.%.

The structure of Sh-2 ceramic is similar. This material is represented by corundum crystals of isometric or short-prismatic shape of size 2 – 6 μm. The intermediate phase fibers grow between the corundum grains, and their crystals size is up to 1 μm. An amorphous phase is absent. The round sealed intercrystal pores of size 3 – 4 μm take up to 2 vol.%.

The wear resistance of milling bodies was estimated based on the following method. A load placed into a porcelain drum of 5 liter capacity included 2 kg of balls, 2 kg of EMC with the average grain size of 100 μm or 2 kg of quartz sand with the average grain size of 500 μm, and 2 liters of distilled water. The grinding of the milling bodies was monitored based on their weight loss after 10 – 50 h of operation with an interval of 10 h.

The abradability was determined according to the following formula:

$$W = \frac{m_0 - m_1}{m_0} \times 100,$$

where m_0 is the initial ball weight; m_1 is the ball weight after milling.

Simultaneously with abradability analysis, the kinetics of milling of quartz sand and EMC was estimated using a Sominskii – Khodakov device to determine the specific surface area of samples of materials taken after each 10 h of milling.

The abrasion rate values in experimental grinding of quartz sand and EMC calculated based on the mean tangent

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TABLE 1

Parameter	Quartz sand	Electromelted corundum
	Sh-2 ceramic	
S_{max}, cm^2/g	41,129	12,374
k	0.032	0.032
v	22.70	15.50
c	– 0.0150	– 0.0162
r	0.990	0.996
S_x	0.10	0.10
	Alubi-90 ceramic	
S_{max}, cm^2/g	37,340	8311
k	0.036	0.037
v	22.47	16.91
c	– 0.0190	– 0.0146
r	0.990	0.995
S_x	0.10	0.10

of the angle made with the abscissa axis in the abradability – milling duration coordinates amounted to 0.008 and 0.018 %/h for Sh-2 ceramic and to 0.006 and 0.030 %/h for Alubit-90 ceramic.

It is seen that the ceramic material developed by us is not inferior to the foreign analog in its wear resistance and even surpasses this analog in milling EMC.

The specific surface areas achieved in 50 h of milling quartz sand with different milling bodies are nearly equal and amount to 16,500 cm^2/g using Sh-2 milling bodies and 17,000 cm^2/g using Alubit-90 ceramics. In grinding EMC these parameters are 5500 and 4500 cm^2/g, respectively. The shape of the kinetic curves is similar as well. In the first 20 h of milling the specific surface area grows insignificantly for both materials subjected to milling and then sharply increases. This trend is true for milling bodies made from both Sh-2 and Alubit-90 materials.

The analysis of published data indicates that no strict mathematical correlation has been established between the specific surface of a material S and its milling duration τ. There exist several equations including empirical coefficients. The most common of them is the exponential equation:

$$\frac{S_{max} - S_0}{S_{max} - S_\tau} = \exp(k\tau),$$

where S_{max} is the maximum achievable specific surface areas; S_0 and S_τ is the specific surface areas at the moment $\tau = 0$ and τ; and k is the empirical coefficient, as well as L. P. Karpilovskii's equation:

$$S_\tau = S_0 + \frac{v\tau}{c\tau + 1},$$

where v is the increment rate of specific surface area at the moment $\tau = 0$; c is the deceleration of the specific surface area increment rate with time.

The analysis of milling kinetics based on these regularities is shown in Table 1. It can be seen that the maximum estimated specific surface area for quartz sand is significantly higher for both types of milling bodies, which is regular. However, it should be noted that using milling bodies Sh-2 the specific surface area of both sand and EMC are on the average 4000 cm^2/g higher than in milling with Alubit-90 balls. The empirical coefficient k is constant in all cases within the calculation error.

The increment rate of specific surface area in milling EMC is slightly lower than milling quartz sand, which is regular, as the latter has lower hardness.

The deceleration of the increment rate of specific surface area with time (coefficient c) is a negative value, which is also regular for the initial milling phase. This parameter is constant within the calculation error regardless of the type of material subject to grinding.

The experimental kinetic curves were subjected to mathematical processing using Advance Grapher Version 2.08 graphic software.

Of all existing models of the dependence of specific surface area on milling duration the maximum correlation coefficient r and the maximum standard deviation S_x are typical of polynomial dependences of the nth power of the form

$$S_{sp} = a_0 + a_1\tau + a_2\tau^2 + ... + a_n\tau^n,$$

where a_0, a_1, a_2, and a_n are empirical coefficients.

The approximation of experimental curves by polynomials of different power indicates that the milling kinetics in the time interval considered is best described by the curves with $n = 5$.

The constancy of the parameters k, c, and n shows that their values primarily characterize the milling mechanism and not the physicochemical properties of material milled. In our case, that is, under fine milling in a ball mill, the main destruction work will be done on abrasion.

The parameters that to a greater extent characterize the properties of the materials involved in the grinding process (the milled and the milling materials) are S_{max}, specific surface area increment rate, and the coefficients a_0, a_1, a_2, ..., a_n in the regression equation.

The difficulty of mathematical approximation of experimental curves (a high value of n) suggests that the milling rate depends on a complex set of parameters, including the ratio between the milling bodies, the material, and the dispersion medium, the mill filling coefficient, the rotational speed of the mill, and the size and shape of the milling bodies. A careful selection of these parameters opens vast possibilities for the intensification of fine milling.

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